546.1

UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH ADMINISTRATION
BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE

Project	Date	Author

SUBJECT—

TITLE

PROGRESS REPORT

EXPERIMENTS WITH AIRPLANE APPLICATIONS OF DDT FOR SPRUCE BUDWORM CONTROL

1947 Season

Wygant ☑
Buchanan ☑
Heard ☐
Massey ☑
McCambridge ☑
---------- ☐
---------- ☐

C. B. Eaton, H. A. Jaynes*, and J. M. Muiry**

Forest Insect Laboratory
Beltsville, Maryland
March 24, 1948

FILE No. _____
Date to: Noted by:

* Forest Insect Laboratory, New Haven, Connecticut
** New York State Conservation Department, Albany, New York

INDEX No.—

U. S. GOVERNMENT PRINTING OFFICE 16—47272-1

P R O G R E S S R E P O R T

EXPERIMENTS WITH AIRPLANE APPLICATIONS OF DDT FOR SPRUCE BUDWORM CONTROL

1947 Season

C. B. Eaton, H. A. Jaynes*, and J. M. Muiry**

Forest Insect Laboratory
Beltsville, Maryland
March 24, 1948

* Forest Insect Laboratory, New Haven, Connecticut.
** New York State Conservation Department, Albany, New York.

TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	2
PREVIOUS WORK	2
1947 STUDIES	3
General Plan	3
Location	3
Participants	4
OBJECTIVES	4
METHODS	5
Plots	5
Selection	5
Survey	7
Sampling Budworm Infestation	7
Larvae	7
Adults	10
Spray Formulations	11
Spray Application	13
Equipment	13
Operating Limitations	15
Procedure	17
TIMING OF TREATMENTS	20
Larvae	20
Adults	21
RESULTS	21
Control of Larvae	21
Control of Adults	23
Effects of Spray on Foliage	23
Effects of Spray on Bird Life	24
DISCUSSION	24
REFERENCES	26

* * * * *

PROGRESS REPORT

EXPERIMENTS WITH AIRPLANE APPLICATIONS OF DDT FOR SPRUCE BUDWORM CONTROL 1947 Season

SUMMARY

The Bureau of Entomology and Plant Quarantine, in cooperation with the New York State Conservation Department, conducted tests during 1947 on airplane spraying with DDT to control larvae and adults of the spruce budworm, Archips fumiferana (Clem.). Approximately 1,800 acres of infested spruce-fir forest located in the vicinity of Cranberry Lake, New York, on lands of the Newton Falls Paper Company and the Draper Corporation, were treated with various dosages of DDT between June 9 and June 19 to control the larvae. On July 14 an additional 180 acres in this general area were sprayed to control the adults.

Oil solutions of DDT applied against fourth and fifth instar larvae during the period of greatest feeding activity were effective in the following dosages per acre: 1/2 pound in 2 gallons, 1 pound in 1 gallon, 1 pound in 2 gallons, and 2 pounds in 3 gallons. The 1 pound in 1/2 gallon per acre dosage was not effective. With the effective dosages, the control obtained ranged from 47.4 to 99.6 percent. The degree of control increased as either the amount of DDT or gallonage of solution per acre increased.

Fifty percent wettable powder (Deenate 50W), applied similarly against the larvae at a rate of 2 pounds of powder in 1 gallon of water per acre was equivalent in effectiveness to comparable dosages of the oil solution; however, serious mechanical difficulties in the mixing and application of this material were encountered.

Dosages per acre of 1 pound in 1 gallon and 2 pounds in 2 gallons of DDT-oil solution did not effectively control the adults. Freshly hatched larvae placed on sprayed foliage the day of spraying and 3 days later were able to spin their hibernacula successfully.

The oil solution produced minor spray burning on some of the hardwood and herbaceous foliage, but did not affect the coniferous foliage.

No deleterious effects of the treatments on bird life were found.

The equipment, methods and procedures used in this study, together with the results obtained, are described in some detail in this report.

INTRODUCTION

In 1945, the spruce budworm (Archips fumiferana (Clem.) was discovered in New York State in considerable numbers. By the end of the 1946 season it could be found wherever spruce and fir occurred in the Adirondack region. About 9,000 square miles were infested in the north central part of the Adirondack State Park of which approximately 3,100 square miles supported a medium to heavy infestation. Airplane spraying in 1947 was conducted in this area. In 1947, a general decrease in the budworm population occurred throughout the infested area in New York. The budworm was more numerous in Vermont in 1947 than in 1946, particularly in the northern counties. There was a considerable increase in Maine in 1947, the insect being reported from 146 towns, compared with 49 in 1946. Caterpillars and pupae were found most commonly in Maine north of Moosehead Lake and in Aroostook County.

Airplane application of highly efficient insecticides such as DDT has become a routine practice for controlling certain forest pests, for example the gypsy moth. However, experience has shown that all forest insects do not succumb to the aerial method of control with equal ease.

While by no means immune to airplane sprays, the spruce budworm has proven to be an insect with which it has been difficult to secure consistently satisfactory results. These difficulties are attributed largely to the concealed mode of existence of the budworm, its inactivity as compared with other defoliators, and the relatively short period when it can be advantageously attacked with insecticides. In view of the possibility that due to the continued spread of the budworm throughout the northeastern states, control recommendations might become necessary, the 1947 experimental program was planned to demonstrate whether or not satisfactory control of this insect with aerially applied DDT sprays could be achieved. It is the purpose of this report to describe how these studies were carried out and what results were obtained.

PREVIOUS WORK

Aerial spraying experiments using DDT to control the spruce budworm have been conducted yearly since 1944 (Nagel & Yuill, 1947). The first tests made during that year in Canada were unsuccessful because the sprays were not applied until the majority of the budworm population had pupated. During the same season, tests in Colorado with ground equipment showed that shoot-feeding larvae could be controlled with 2.5 pounds of DDT per acre. In 1945, airplane spray experiments with DDT were conducted in Canada, New York, and Colorado against various stages of the spruce budworm. The results were somewhat variable, but it was concluded that between 1 and 3 pounds of DDT per acre were required to control needle-mining larvae, and about 2 pounds of DDT per acre for shoot-feeding larvae. Control of the adult moths with DDT sprays was unsatisfactory.

In 1946, aerial spraying experiments were limited to intensive studies on small (20 acre) strip and block plots in northern New York. Results of tests with solutions, emulsions, and suspensions of DDT were again somewhat variable, due to irregularities in the spray deposit and in the budworm population. However, this work indicated that: (1) oil solutions of DDT are superior to suspensions or emulsions; (2) a dosage of 1 pound or less of DDT per acre will give satisfactory control if distributed in more than 1 gallon of liquid per acre; (3) finely atomized sprays are more effective than coarse sprays, provided the drops are not so small as to be lost by drift or evaporation; (4) budworm larvae are most vulnerable to insecticidal action during the two or three week period when they are actively feeding in developing shoots; and (5) spot burning of foliage may result from spray treatments, but damage thus far has not been serious.

In general it may be said that the aerial spraying experiments conducted during the period 1944 through 1946 demonstrated that DDT was highly toxic to the spruce budworm, and showed that on the basis of results from tests on small plots, airplane spraying offered considerable promise as a method for controlling epidemic outbreaks of this insect.

1947 Studies

General Plan

To test the validity of conclusions drawn from the earlier studies under conditions approaching those that would be encountered in a control operation, a selected number of treatments were applied to test units generally somewhat larger than those that had been used previously. Replication of the treatments was considered mandatory in view of the variable results obtained in previous work. To determine the degree of control obtained in these tests, a system for sampling the budworm population before and after spraying was employed, that would show for each plot the population reduction resulting from the treatment.

Location

The use of large plots and replication of the different treatments necessitated the choice of a site for the experiments of approximately 2,000 to 3,000 acres in size, suitable with respect to forest type, budworm infestation and proximity to a landing strip. An area meeting these requirements was selected in the fall of 1946 by R. C. Brown, H. J. MacAloney and J. S. Yuill near Cranberry Lake, New York. The area chosen was on private timberland owned in part by the Draper Corporation, Tupper Lake, New York and in part by the Newton Falls Paper Company, Newton Falls, New York. It was estimated that the holdings of the two companies in the vicinity of Cranberry Lake contained a sufficient area of balsam and spruce for the tests, and that the 1946 infestation had been heavy. A small grass surfaced emergency landing strip, about 2,000 feet long, was located in the approximate center of the area on property of the

Newton Falls Paper Company. The companies involved indicated their willingness to permit use of their timberlands for the spray tests. Accordingly, field operations were conducted in this area from mid-May to August.

Participants

The study was undertaken jointly by the New York State Conservation Department, and the Beltsville, Maryland, and New Haven, Connecticut Forest Insect Laboratories of the Bureau of Entomology and Plant Quarantine. Cooperating were the Draper Corporation and the Newton Falls Paper Company referred to above. At the instigation of the Fish and Wildlife Service, U. S. Department of Interior, E. R. Simmons, a graduate student at Cornell University, was interested in studying the effects of the spraying on bird life in some of the treated areas.

Personnel assigned to the project were as follows: New York State- J. N. Muiry, assisted by E. C. Wixson, Victor Schrader, Charles Gordon, Clarence Scott, Donald Gilroy and Robert Bennet; New Haven Laboratory- H. A. Jaynes assisted by J. A. Beal, David Crosby, J. L. Bean, E. J. Duda, and W. E. Waters; Beltsville Laboratory- C. B. Eaton assisted by J. M. Davis, J. P. Secrest, W. E. Bullard, G. H. Pierce, C. A. Weigel, W. F. McCambridge, and pilots E. C. Baker and M. M. Clarke. Ranger William Doran of the New York State Conservation Department and Forester S. R. Parmelee of the Draper Corporation were particularly helpful in facilitating the initial phases of the work.

The activities of the various units participating in the experiments were as follows: the New York State group located and mapped the plots, marked the boundaries, and erected temporary markers on the plot corners to permit their location from the air. The New Haven group conducted the budworm population surveys on the plots before and after treatment, and indicated when insect development had progressed to the point where spraying operations could start. The Beltsville group furnished the equipment for handling the spray and was responsible for all phases of the preparation and application of the various dosages tested. The DDT and the auxiliary solvent used were furnished by the Beltsville laboratory, while the fuel was supplied by New York State. The performance and completion on schedule of the entire operation was in no small part due to the excellent cooperative spirit that prevailed among all parties concerned. This made possible the ready interchange of equipment and manpower as day to day needs required.

OBJECTIVES

The specific objectives of the experiments were twofold: first, it was desired to test several combinations of DDT sprays against shoot-feeding larvae; and second, to test one or two dosages against the adult moths.

The DDT sprays and dosages selected for tests against the larvae were:

1. DDT in oil solution

   a. 1 pound in 1/2 gallon per acre.
   b. 1/2 " " 2 gallons per acre.
   c. 1 " " 1 gallon per acre.
   d. 1 " " 2 gallons per acre.
   e. 2 " " 3 gallons per acre.

2. 50 percent wettable DDT in water

   a. 1 pound in 1 gallon per acre.
   b. 2 pounds in 2 gallons per acre.

Because previous experiments with some of these sprays showed greater promise of producing results against the larvae than against the adults, considerably more emphasis was placed on tests with the former than with the latter. Replication was undertaken only in the larval treatments, and was accomplished by dividing the plots into two series and applying the entire range of dosages to the first series before treating the second.

METHODS

Plots

Selection.

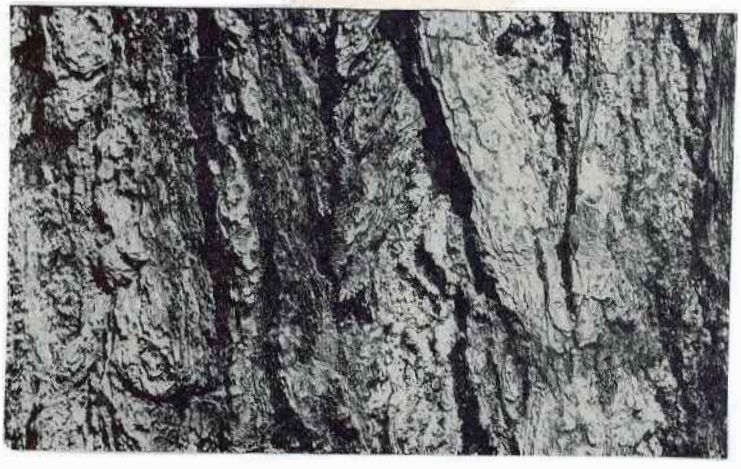
Type maps showing the spruce-fir areas were kindly furnished by the two lumber companies on whose property the spraying was to be done. Tentative plots were laid out upon these maps with the idea of obtaining blocks of spruce-fir as large as possible for the various treatments to be applied. Many of the proposed plots were over 200 acres in size with two of them over 400 acres. However, upon examining the area in early May it was found that considerable hardwood areas were intermixed with the spruce-fir types and that suitable softwood areas were not as large as indicated on the type maps. There was considerable variation in the forest type in the region, ranging from black spruce swamp to spruce-hardwood type. The softwoods were localized along the streams and low lying areas, while the small ridges and hills were composed mostly of the beech, birch, maple hardwood types. (Figure 1)

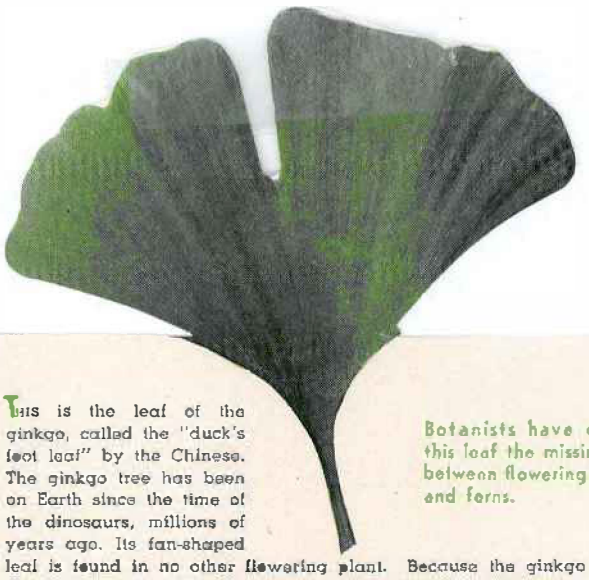
There was evidence of a fair amount of budworm defoliation in 1946 on the balsam throughout this section. Sampling for budworm infestation in 1947 just before spraying showed that there was a variation from 0.74 to 5.66 budworms per 15-inch sample in the plots. The infestation being heaviest to the east near the Massawepie Club. Two check areas were selected,

one on the west side with only 0.44 budworm per sample while the one to the east had 4.58 budworms per sample. Although the budworm infestation was light in some plots it is thought to have been adequate to test the efficiency of the spray.

Figure 1.--Plot locations were limited by the distribution of the infested forest type along streams and low lying areas.

The bark of the ginkgo is fissured into ridges of irregular shape and an old tree is deeply furrowed.





This is the leaf of the ginkgo, called the "duck's foot leaf" by the Chinese. The ginkgo tree has been on Earth since the time of the dinosaurs, millions of years ago. Its fan-shaped leaf is found in no other flowering plant. Because the ginkgo is resistant to insect or fungus attack, it is especially desirable as an ornamental or street shade tree. Its bark is pictured on the other side.

Botanists have called this leaf the missing link between flowering plants and ferns.

WRITE to The American Forestry Association for further information about the ginkgo or any other tree.

THE AMERICAN FORESTRY ASSOCIATION

919 Seventeenth Street, N. W. Washington 6, D. C.

The plots were so situated that one side of half the plots bordered or was close to roads that could be traveled by conventional automobiles. The others were near roads or trails on which only four-wheel drive trucks or jeeps could travel most of the time. If such vehicles had not been available it would have been impossible to survey and sample the plots with the men available.

Fourteen plots varying in size from 42 to 314 acres were established for spraying while two additional areas, sufficiently removed from the treated plots to avoid contamination due to drift, were used as checks Figure 2. The majority of the plots were made rectangular in shape even if areas of pure hardwoods were included in order to aid the pilot in applying the spray.

Survey.

A preliminary survey was made of each plot to ascertain the extent of the spruce-fir stand in order to determine where the boundaries should be established. This required considerable time as the proposed boundaries often had to be extended or shifted in order to include more spruce-fir or eliminate some of the hardwoods. In some plots large streams or swamps necessitated off-sets in running the lines, thus slowing up the work.

The boundaries of each plot were marked at relatively short intervals with spots of yellow paint on trees in order to aid the sampling crews and to facilitate locating the plot the following season. Compass bearings were taken on the boundary lines and the plots were sketched on enlarged Geological Survey sheets for the use of the pilots. Plot corners and midpoints of long boundaries were marked with white wind socks (Figure 3) or white canvas bags stuffed with brush and tied to the tops of trees (Figure 4) to aid the pilots in locating the plots.

Sampling Budworm Infestation

Larvae.

The budworm population was measured before and after treatment in the sprayed and in the unsprayed check areas. Trees to be sampled were located on a line running diagonally across the plot. It is believed this gave a better distribution of samples than by running lines perpendicular to the sides of the plot. Regardless of the flight direction of the plane the diagonal line was across and not parallel with the flight. Each sample tree was marked with a 2-inch band of orange cloth at breast height to aid the sampling crew. All sample trees were numbered by using a shipping tag tied to the cloth band. Spruce and fir were selected in proportion to their occurrence in the stand, but sampling was restricted to trees having a sufficient number of branches at a height of 18 to 20 feet to permit the removal of several 15-inch twigs.

Figure 2

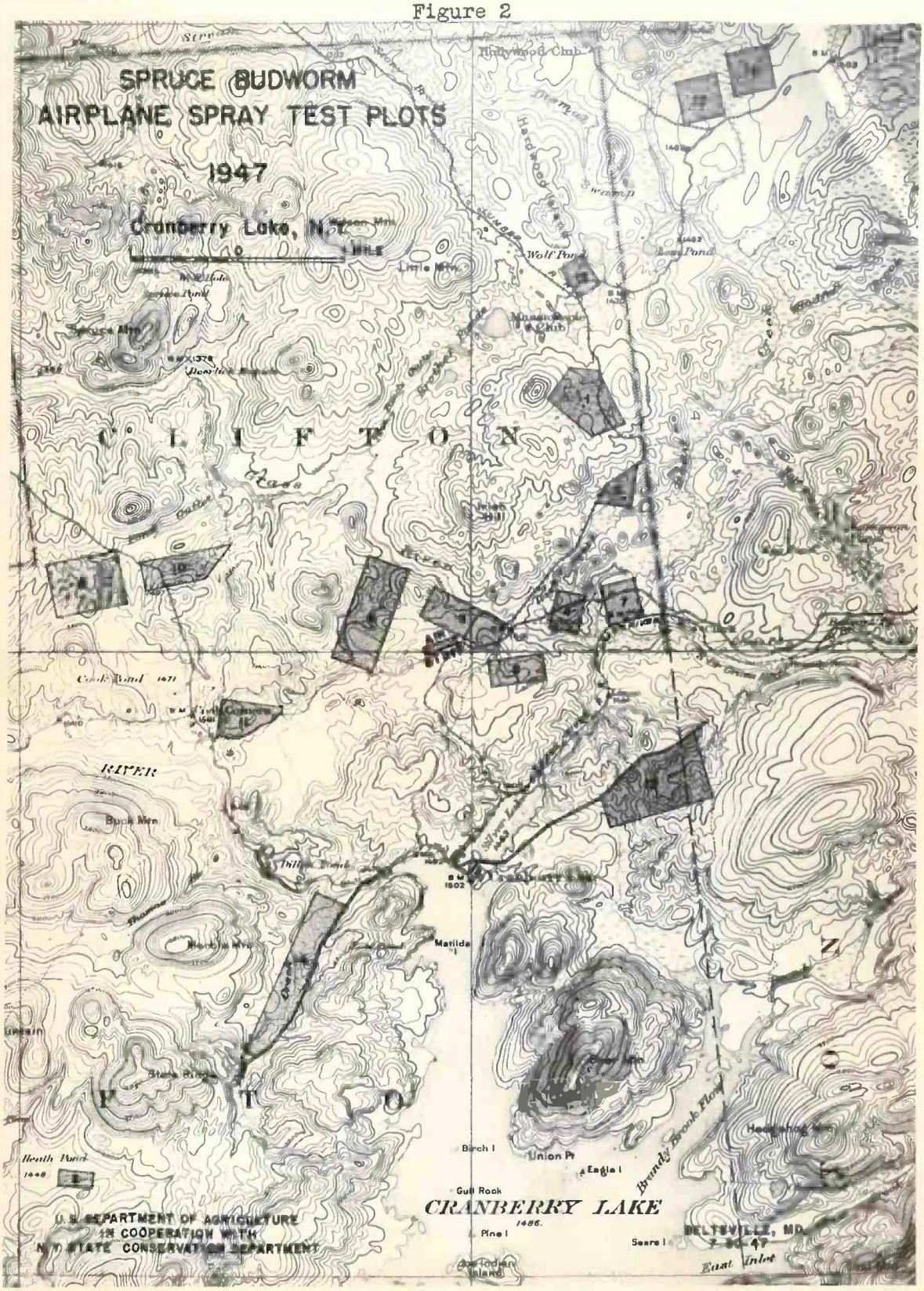

SPRUCE BUDWORM
AIRPLANE SPRAY TEST PLOTS
1947
Cranberry Lake, N.Y.
1 Mile
Hollywood Club
Wolf Pond
Little Mtn.
Spruce Mtn.
C L I F T O N
Union
Buck Mtn.
Matilda
Matilda Mtn.
Stony Ridge
P O T
Heath Point
Birch I
Union Pt
Eagle I
Gull Rock
CRANBERRY LAKE
1486.
Pine I
Bear I
Brandy Brook Flow
East Inlet
U. S. DEPARTMENT OF AGRICULTURE
IN COOPERATION WITH
N.Y. STATE CONSERVATION DEPARTMENT
BELTSVILLE, MD.
2-20-47

Figure 3.--Windsock used to mark corners of plots and midpoints of long boundaries.

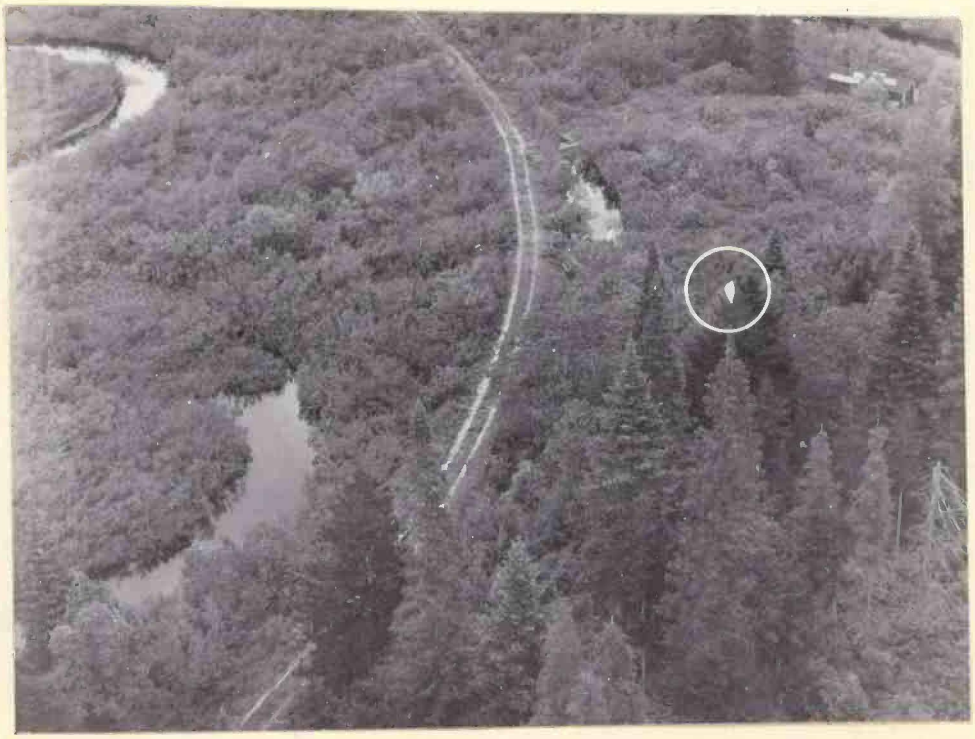


Figure 4.--Alternative to windsock markers, white grain sacks stuffed with brush were used.

The sample trees were spaced 90 to 130 feet apart, with the first and last trees usually about 100 feet from the plot corners. Under this system 50 trees were sampled on the larger plots and 25 on the smaller plots. The pre-treatment samples consisted of two 15-inch twig samples from each tree while the post-treatment samples consisted of four 15-inch twigs from each tree.

When the sample trees in each plot were selected a record was taken of the tree species, crown class and stand condition, whether open or closed. In sampling, a record was kept of the larvae and pupae found on each twig sample from each tree. This indicated if there was a difference in infestation on the various species of trees, and particularly to what extent control was obtained in the different types and stands.

In taking the pre-treatment samples a 15-foot aluminum extension pole pruner was used. The two 15-inch samples from each tree were labeled with the tree number and placed in a cloth collecting bag. The larvae at this time were small and within the expanding bud. These samples were taken to a field laboratory where they were carefully examined and the number of budworms found on each twig recorded.

After spraying, the larval drop was determined from collections on cloth sheets placed beneath infested trees on each plot. One week after spraying, when most of the affected larvae had fallen, the post-treatment samples were taken. In the post-treatment sampling four 15-inch twig samples were clipped from each sample tree. These were collected in a net suspended at the top of the pole pruner and carefully lowered to the ground so as not to lose any of the larvae. These twigs were examined in the field and the larvae and pupae recorded. To further evaluate the effects of the spray, five medium-sized, heavily infested trees on the larger plots and three similar trees on the smaller plots were cut and carefully examined for the presence of surviving larvae.

It is thought that the sampling system used was adequate to furnish a measure of budworm mortality caused by the spray in most of the stands treated. However, where aerial sprays are applied to large trees in closed stands, this method of sampling should give a conservative estimate of the effects of the insecticide, since the upper canopy would intercept much of the spray. The survival of larvae within reach of the pole pruner thus might be higher than that in the upper parts of the trees.

Adults.

In order to evaluate the results of spraying two of the plots for the control of budworm moths, 9 cloth sheets, 3 feet by 6 feet, were placed in each plot prior to spraying. Observations were made during spraying operations and immediately following the application. Observations were continued the following week, in order to determine the residual effect of the spraying on the moths. Four balsam fir branches 18 inches long were taken a few hours after application from trees that were known to

have been sprayed from each of the two sprayed plots. Four similar branches were collected from a non-sprayed area. These branches were placed in three small cages and 50 moths were placed in each cage to determine if the residue was sufficient to kill the moths. Three days later the experiment was repeated.

Five twig tips from different branches in each of the sprayed plots and check area were taken on the day of spraying and three days later. These twigs were placed in glass vials and 25 freshly hatched larvae were then placed in each vial. These twigs were examined in mid-August for hibernacula to determine if the residue was sufficient to kill the hatching larvae before they formed their hibernacula.

Spray Formulations

Two kinds of DDT preparations were tested, viz., DDT in oil solution and DDT in water suspension.

The solution consisted of technical grade DDT dissolved in a hydrocarbon auxiliary solvent and No. 2 fuel oil. Because of delays in securing delivery prior to the time when treatments were scheduled to begin, two different auxiliary solvents, similar in general characteristics, were used. These were Velsicol AR-50, and a product of the Socony-Vacuum Corporation designated No. 1861. Difficulties inherent to mixing technical grade DDT under field conditions were avoided by preparing a concentrate of the material considerably ahead of the time when it was to be applied, and making the final dilution with fuel oil just prior to loading the plane. The basic formula used in preparing the concentrate, from which all final dilutions for the different rates of application were made, was 1 pound of DDT in 1.4 quarts of auxiliary solvent. The concentrate was mixed at Saratoga Springs, N. Y. with one of the mobile conversion units owned by the New York State Conservation Department. This unit consisted of an orchard sprayer with two 150-gallon tanks equipped with agitators, and a pump mounted on a truck. Power for this unit was furnished by the truck motor, and heat for warming the solution to 85° or 90° F. during the mixing process was derived from water circulated from the truck radiator back through pipes in the tanks. The concentrate was put up in drum lots and trucked to the airstrip at Cranberry Lake. Dilution of the finished spray with fuel oil and loading of the planes was accomplished with a portable, gasoline-driven, centrifugal pump (Figure 5). In diluting the concentrated spray the practice was adopted of mixing the quantity required for each plot the day before it was to be applied. The volume of spray made up was based on the dosage and acreage involved with an excess of about 10 percent allowed for timing errors in release of the spray at the beginning and end of each swath.

The suspension contained a wettable powder (Deenate 50 W manufactured by duPont) consisting of 50 percent DDT and 50 percent inert materials diluted with water. While this spray was easy to prepare, considerable difficulty was experienced in handling the finished material. In the concentration

used (2 pounds to 1 gallon) the spray when freshly prepared had the consistency of a thick mixture of paint. Unless used immediately after mixing, the material settled to the bottom of the mixing container and could not be resuspended either by pumping or ladling. The loading pump handled this material with difficulty even when it was freshly prepared, and clogging of the spray apparatus on the plane was a constant threat during the course of operations. It was necessary to thoroughly flush out all spray equipment with clean water immediately after using the suspension.

The formulation of the various dosages and the volume of spray applied to each plot are listed in Table 1.

Table 1.--Dosage and Volume of Spray per Plot for 1947 Spruce Budworm Aerial Spray Tests.

Plot No.	Dosage per Acre: DDT (lbs.)	Auxiliary Solvent (qts.)	Total Solution (gals.)	Area Treated (acres)	Total Volume Spray Applied (gals.)	Overrun Allowance (gals.)
	Tech Grade	Soc.-Vac. 1861	Fuel Oil			
8	0.5	0.7	2	80	170	10
10	0.5	0.7	2	116	250	18
6	1	1.4	0.5	253	141	14.5
16	1	1.4	1	90	104	14
1	1	1.4	2	170	376	36
17	2	2.8	2	90	208	28
		Velsicol AR-50				
2	0.5	0.7	2	42	94	10
11	0.5	0.7	2	82	188	24
12	1	1.4	1	314	353	39
14	1	1.4	1	254	282	28
5	1	1.4	2	140	306	26
		Soc.-Vac. 1861 & Velsicol AR-50				
9	2	2.4	3	208	660	36
	50% Wettable Powder	None	Water			
4	2	--	1	58	21*	0**
7	2	--	1	73	73	0**

* Treated only one-fourth of plot due to shortage of spray materials.
** Overrun allowance omitted because of shortage of spray materials.

Figure 5.--Loading finished spray into plane at the airstrip, using centrifugal loading pump.

Spray Application

Equipment.

Two trainer type biplanes, an N3N (NR-44811) and a Stearman (NX-3207) were used to distribute the spray. Figure 6. Normally quite similar without spraying equipment, these two planes differed in that the N3N carried an internally mounted spray tank located in the front cockpit, while the Stearman bore an experimental model external tank mounted beneath the fuselage. With space only for the pilot, the N3N was limited entirely to spray work; however, the Stearman having both cockpits unencumbered, was used for both reconnaissance and photographic work in addition to spraying. The presence of a two-place plane proved to be a distinct advantage throughout the operation, for in several instances it was necessary for one of the ground crew to assist the pilot in locating various plots from the air. However, the performance of the Stearman was not considered by the pilots to be as satisfactory as that of the N3N, due principally to the drag created by the external tank.

Aside from the location of the spray tank, the equipment with which these planes were fitted was essentially identical. It consisted of a 60-gallon spray reservoir, a tubular steel boom fitted with nozzles and suspended beneath the lower wing, and a centrifugal pump driven by a four-bladed wooden propeller, by means of which the spray was transferred from the tank

Figure 6.--N3N (left) and Stearman (right) spray planes used in 1947 spruce budworm spraying experiments.

into the boom under positive pressure. A relief valve mounted on the discharge side of the pump was used to regulate the pressure during spraying. Agitation of the spray liquid was accomplished by means of a bypass line carrying the overflow from the pressure relief valve into the bottom of the tank. The spray nozzles used were a commercial type (Spraying Systems Company, B-5) having a 1/8-inch orifice and producing a hollow cone spray pattern. These nozzles were selected on the basis of their superior performance in comparison to other types of nozzles tested at Beltsville, Maryland.

The spraying characteristics of the equipment were known from numerous experimental flights made at Beltsville in 1946 and 1947. These tests showed that with B-5 nozzles about 95 percent of the total volume of spray recovered was deposited in drops ranging in diameter from 100 to 450 microns, and indicated that an effective swath width of 132 feet could be expected. With a 132-foot swath, the output of spray required at normal operating speed (80 miles per hour) was 22.5 gallons per minute for a dosage of 1 gallon per acre. Thirty nozzles on the Stearman were needed to produce this output, while 32 were required on the N3N. To halve this flow rate, as was necessary in the 1 pound in 1/2 gallon treatment, one-half the number of nozzles were used. To double or triple the volume of spray applied, multiple flights were made, as described below. The pressure relief valve was set to provide a constant pressure of 25 pounds per square inch on the liquid during spraying, regardless of flow rate.

Operating Limitations.

Spraying operations were centralized at the emergency landing strip within the experimental area. Figure 7. While not frequently used by planes, this field was the only location suitable for the purpose within a radius of 14 miles. The stip proper was unimproved sod farmland, overgrown with grass and surrounded by forest. The useable runway was 1600 feet in length, but somewhat rough, particularly in the middle. It was approachable from the air only from the southwest or northeast directions. In the initial spray flights the planes were operated with a full load of spray, but with a reduced gas load due to the condition of the strip. However, as the pilots became accustomed to the terrain, full loads of both gas and spray were carried routinely.

No mean feat in itself was successful approach via vehicle to the airfield, or in fact to any of the plots not located on main roads. Excessive rainfall during the spring converted many of the truck trails to quagmire, for passage over which the four-wheel drive vehicles available proved indispensable. Spray supplies totaling about 3,200 gallons, together with aviation gasoline, oil, and miscellaneous equipment needed to handle the spray and service the planes were centered at the field. Also established there was a temporary camp to accommodate the two-man guard maintained to protect equipment at times when operations were not under way.

Figure 7.--Airstrip near Cranberry Lake, N. Y., used as a base of operations in 1947 spruce budworm spraying experiments.

Weather factors affecting airplane spraying operations in the general area were measured at a weather station established at the airstrip. Wind direction and wind velocity were measured at 40 feet above the ground, while air temperature and relative humidity were measured at 5 feet above the ground. Temperature inversion between the lower and upper levels was measured with telethermometric equipment. Wind direction was noted from drift of the wind sock, and velocity from anemometer readings. Air temperature and relative humidity were determined with a sling psychometer. During the periods when spraying flights were in progress these measurements were taken at intervals of one-half hour. A summary of the records obtained is presented in Table 2.

Spray flights were generally limited to periods when the wind velocity did not exceed 5 miles per hour, and with one exception were restricted to early morning, when temperature inversion is most likely. No treatments were made when the foliage was dripping wet, and in no case did heavy rains fall before the spray had a chance to dry.

Table 2.--Summary of Weather Data Recorded at Cranberry Lake Airstrip During Treatment of Spruce Budworm Aerial Spray Plots.

Date	Spraying Period (hours)	Plots Treated	Mean Wind Velocity (mph)	Mean Air Temperature (°F.)	Mean Rel. Humidity (%)	Prevailing Wind
June 9	1615 - 1945	8 & 10	2.5	59.7	73	NW
11	0515 - 0815	1 & 6	3.8	74.7	82	SW
13	0515 - 0815	14	2.3	48.3	97	E
17	0530 - 0830	2,5 & 11	4.4	52.3	69	W
18	0630 - 1000	9	4.5	56.8	69	W
19	0530 - 0800	4,7 & 12	1.7	48.8	93	NW
July 14	0539 - 1000	16 & 17	2.4	66.4	80	E

Procedure.

The marking, sampling, and flight pattern plan for a typical plot, with an oblique photograph of the main body of the plot is shown in Figure 8. The adoption of certain routines to assist the pilot in applying the spray was found essential as the treatments got under way. With the plot corners well marked by wind socks or bags, and a master map showing the shape and relative position of each area, location of the plots from the air was greatly simplified. Before each plot was treated, the pilot assigned made "dry runs" over the area to familiarize himself with the problems to be encountered. Simultaneously, the crew scheduled to handle swath markers traversed the boundary to be used for this purpose. When air and ground reconnaissance were completed, a sketch map was prepared showing flight direction, location of swath markers, and number of swaths to be flown with each load. Adoption of these practices helped eliminate some of the areas that might have been missed or heavily overdosed. Since radio communication was lacking, both pilot and ground crew were furnished with copies of the sketch map, and were briefed in detail on the procedure to be followed. While the above procedure helped minimize confusion between all parties concerned, it proved no substitute for a satisfactory means of communication.

For marking the swaths, balloons filled with helium were used at one end of the plot and successive balloon locations were determined by pacing. Where roads or other open areas bordered on the plots it was possible to move the balloon rapidly enough to mark the center of each 2-chain swath. In many cases however, cleared boundaries were not available and it was necessary to let the balloon up through openings in the forest canopy. Undergrowth usually prevented rapid transfer of the balloon from swath to swath under these conditions and spacing of successive spray runs after the initial flight for each load was left to the pilots' judgment. When the required number of swaths per load had been distributed, the pilot passed over the balloon crew and "gunned" the motor signifying his return to the airstrip to reload. While reloading was in progress the balloon was moved to the correct location for the beginning of the next load. Generally not more than three swaths were applied between balloon stations.

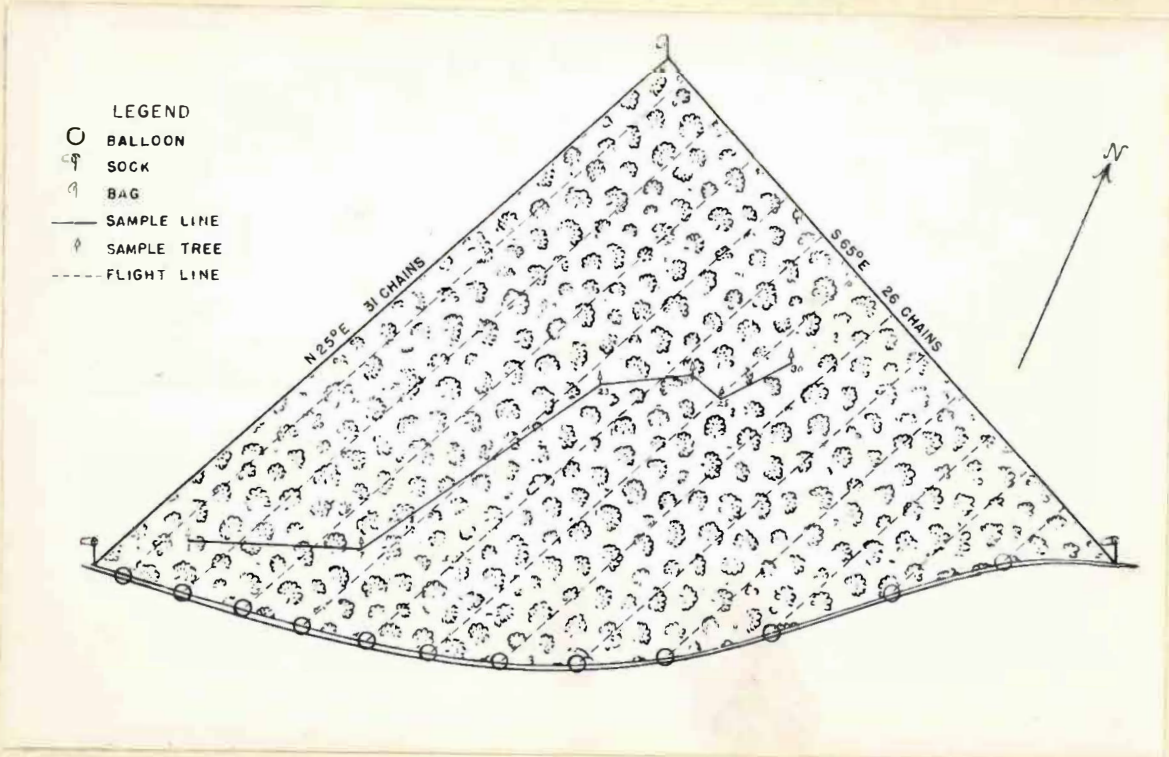


Figure 8.--Above- oblique view of the central portion of one of the spray plots. Below- diagram of marking, sampling and spray application procedure on this particular plot.

Although the balloon markers were quite fragile and easily punctured, their use in forested areas was made more practical through methods developed by J. M. Davis. A reel for rapidly letting up or retrieving the balloon was constructed by substituting a discarded movie film spool for the grinding wheel on a hand grinder. Figure 9. With this apparatus

Figure 9.--Balloon used as swath marker attached to high speed reel devised by J. M. Davis.

the balloon could be let up rapidly above the canopy for the pilot to see at the beginning of his spray runs, and retrieved before the plane passed over the marked point. A portable cylinder with helium for 5 or 6 spare balloons was also carried by the marking crew. Where an inflated balloon was lost or could not be carried through dense undergrowth, the crew moved to the next swath and inflated one of the spare balloons. Figure 10. The use of light-weight protective covers for the balloons did not prove successful.

Spray flights were made at altitudes ranging from near tree top level to 30 or 40 feet above the canopy, depending on the terrain and presence or absence of tall snags. Direction of flight was governed by the topography and shape of each plot, but in most cases spray flights were made parallel

Figure 10.--Portable helium cylinder carried by balloon crew contains enough helium to inflate 5 or 6 spare balloons.

to the long axis of the treated area to reduce the amount of turning required by numerous short runs. The beginning of each swath was determined from the position of the balloon marker, while corner markers enabled the pilot to align each swath and determine when to shut off the spray. Spray flights both away from and toward the balloon line did not prove successful since excessive errors in alignment usually occurred on the return run. Plots treated at the rate of one gallon per acre or less were covered once by successive spray flights at 2-chain intervals. Treatments of two gallons per acre or more were applied by flying the area two or more times at this swath interval until the desired volume of spray was distributed. Multiple coverage was obtained in some cases by flying one plane over the area the requisite number of times, while in other cases tandem flights were made using two planes--one acting as leader while the other occupied the wing position.

TIMING OF TREATMENTS

Larvae

Daily observations and counts were made of the budworm larvae in order to ascertain the proper time to apply the spray. The most effective time would be when the majority of the larvae were most exposed to spray and during the period of greatest feeding activity. In the Adirondacks this period was from June 9 to June 19 inclusive, during which time the spray was applied. On June 4 the pollen had been shed from the staminate

flowers and the vegetative shoots had elongated with the needles beginning to separate. Thus the larvae were more exposed. On June 9 the majority of the budworm larvae were in the 4th instar with some in the 5th. By June 19 the majority of the budworm were in the 6th and 7th larval instar, with some in the 5th and very few in the pupal stage.

Adults

Between July 6 and 17, collections of 200 to 400 budworm pupae were made almost daily in the vicinity of the plots to be sprayed for moth control, to ascertain the percentage of emergence of moths. On July 14, when the plots were sprayed, 50 percent or more of the pupae had produced adults. By July 15, 73 percent and on July 17, 92 percent had produced moths. On July 11 the first egg cluster was found in the field, thus the spray was applied when moths were very numerous but few egg clusters had been laid.

RESULTS

Control of Larvae

The results in controlling the larvae of the spruce budworm by aerial application of spray are shown in Table 3. The percent reduction (excluding natural mortality) in budworm population between pre-treatment and post-treatment sampling on the sprayed plots was computed by use of the following formula:

$$\text{Percent reduction equals} \quad 100 \left(1 - \frac{TA \times CB}{TB \times CA} \right)$$

where CB equals check plot count before spraying
CA equals check plot count after spraying
TB equals treated plot count before spraying
TA equals treated plot count after spraying

The data from check plot 15 only were used in computing the percent reduction on the treated plots, since sampling indicated that the population on check plot 3 was excessively low in comparison to that on the other areas included in the study.

The population reductions obtained for the various treatments indicate that the effectiveness of the sprays increased as the amount of DDT and the gallonage of the solution per acre were increased. More even distribution of the spray was obtained by flying over an area two or more times. The application of 1 pound of DDT in 1/2 gallon per acre caused little larval mortality, but 2 pounds in 3 gallons per acre in three applications resulted in practically complete control. A study of the population reductions for the various treatments in relation to the timing of spray application indicates that the late sprays were slightly more effective than the early sprays; however, it is doubtful whether the data are conclusive on this point.

Table 3.--Summary of Tests with Airplane Sprays for the Control of Spruce Budworm Larvae.

Plot No.	Dosage per Acre: DDT (lbs.)	Dosage per Acre: Total Solution (gals.)	Area Treated (acres)	Date of Spraying	No. Larvae per 100 15-inch samples: Before Spraying	No. Larvae per 100 15-inch samples: After Spraying	Percent Reduction: Total Mortality	Percent Reduction: Excluding Natural Mortality	Estimated No. Larvae surviving Per Tree
	Tech. Grade	Fuel Oil		June					
6	1	1/2	253	11	375	319.0	14.9	none	347
10	1/2	2	116	9	424	168.0	60.4	47.4	110
8	1/2	2	80	9	310	77.0	75.2	67.0	72
11	1/2	2	82	17	74	17.0	77.0	69.6	10
2	1/2	2	42	17	153	16.6	89.2	85.6	17
14	1	1	254	13	99	10.5	89.4	85.9	10
12	1	1	314	19	143	17.5	87.8	83.8	6
1	1	2	170	11	269	18.5	93.1	90.9	13
5	1	2	140	17	424	13.5	96.8	95.8	3
9	2	3	208	18	174	0.5	99.7	99.6	0
	50% Wettable	Water							
7	2	1	72	19	566	45	92.1	89.5	42
4	2	1	58	19	388	58	85.0	80.1	68
	None	None							
15	Check Plot		--	--	458	345	24.7	--	480
3*	Check Plot		--	--	44	22	50.0	--	9

* Data from this plot omitted in computing percent reduction (excluding natural mortality) on treated plots, because of excessively low budworm population.

A statistical analysis of the data obtained in these experiments was made by R. F. Anderson*. The latter reported that statistically the 1 pound in 1/2 gallon per acre treatment was definitely less effective than the other treatments and was not significantly better than the untreated area. Statistical significance was found in the effectiveness of all other treatments as compared to the check area, but because of variations in the samples and lack of more replicates, statistical differences between these treatments could not be demonstrated. Since it was not practical to replicate treatments sufficiently in these studies to satisfy the requirements for statistical treatment of the data, and at the same time meet other limitations imposed on the experiment, the results of the analysis are not entirely unexpected. It seems unlikely, however, that increases in the degree of control obtained, corresponding to increases in in dosage, as demonstrated by the data, would occur solely by chance.

Control of Adults

In the plot where 1 pound of DDT in 1 gallon of solution per acre was applied against the moth, the first evidence of the adults being affected was noted about 55 minutes after application, while in the plot which received 2 pounds of DDT in 2 gallons per acre, the effects of the spray were noted 17 minutes after the spray was applied. Two to 3 days later practically no moths could be found in the area receiving the heavier dosage. There were, however, many moths in the area receiving the lighter dosage, but not as many as were present in the adjacent unsprayed area.

The results from placing moths in cages with sprayed and non-sprayed foliage substantiated the field observations. On July 17 the cages in which 50 moths had been placed on July 14 were examined. Only one dead moth was found in the check cage, six dead moths in the cage containing foliage receiving the 2 pound treatment. Fifty or more egg clusters were found in each cage. This experiment was repeated on July 17 with freshly cut foliage at which time 74 moths were placed in each cage. On July 21 there were five dead moths in the check cage, six dead moths in the cage with foliage from the 1 pound-1 gallon plot, and 22 dead moths in the cage with foliage from the 2 pound-2 gallon plot. There were 159, 145, and 109 egg clusters on the foliage in the above cages, respectively.

When the twigs in glass vials from the sprayed plots and the check area, in which freshly hatched larvae had been placed, were examined, it was found that a large proportion of the young larvae on the sprayed foliage had spun their hibernacula and were alive.

Effects of Spray on Foliage

Some spray burning was noted on hardwood and herbaceous foliage on plots receiving 1 or 2 gallons of oil solution spray per acre, and severe burning on foliage of this type was found on the plot treated with 3 gallons of

* Entomologist, Forest Insect Investigations Division, Beltsville, Md.

solution per acre. It is believed that the foliage injury was caused by a concentration of large drops which usually fall in the center of each swath. Spray burning on coniferous foliage was not observed either immediately after the spraying or three months later when several of the more heavily treated plots were examined for evidence of delayed injury that sometimes results from the use of oil sprays on conifers. Delayed burning was not evident this year on plots sprayed near Lake Clear in 1946.

Effects of Spray on Bird Life

Studies on a portion of one of the plots treated with 1 pound DDT in 1 gallon of oil solution per acre, where a fairly heavy bird population existed, failed to reveal any damaging effects of the chemical on either the adult or nestling birds. An examination of some of the budworm areas near Lake Clear, New York, sprayed in 1946, where bird studies were conducted by George and Mitchell (1947) did not reveal any permanent effect of the treatment on the bird population.*

DISCUSSION

The budworm population in the area in which the 1947 experiments were conducted was somewhat lighter than had been anticipated, and was in no way comparable to the tree-killing outbreaks that have occurred in Canada. This limitation notwithstanding, it is believed that the infestation was adequate to test the efficacy of the sprays. Trial of the sprays under conditions of light infestation may have been more critical than their testing under epidemic conditions, for if satisfactory control can be obtained where the population is scattered it is likely that a denser population would be more drastically affected.

The methods used in these studies, particularly the marking system employed in connection with the spray flights, entailed considerably more detail than would be practical or necessary in an extensive control operation. The purpose of these refinements was to reduce sources of error in order to obtain more clearcut comparisons of the different sprays.

The degree of control achieved in the 1947 treatments against the larvae is in no small part due to the knowledge accumulated from previous seasons' aerial spraying work with this insect. The spray formulations, dosages, degree of atomization required, and timing of the sprays in the current experiments were predicated on conclusions drawn from the 1946 studies. The oil solution did not prove to be markedly superior to the suspensions in equivalent quantities, but mechanical difficulties in handling the latter probably will preclude their use in their present

* From personal communication by E. R. Simmons, Cornell University, Ithaca, N. Y. to Dr. Joseph P. Linduska, Patuxent Research Refuge, Laurel, Md. dated Dec. 2, 1947.

form for aerial spray work. The application of 1 pound DDT in 1/2 gallon per acre, in conformance with inferences previously drawn, did not provide enough liquid carrier to produce satisfactory control. Likewise the finer atomization of the nozzles used this year in contrast to that from larger nozzles used in 1946, probably resulted in better coverage with the insecticide. Application of the sprays while the larvae were in the shoot-feeding stage and most exposed (the most suitable timing on the basis of previous work) undoubtedly accounted in a large measure for the degree of control obtained.

The dosages tested against the larvae, other than the 1 pound DDT in 1/2 gallon per acre, gave progressively greater control as the quantity of DDT and volume per acre were increased. In considering these results, it should be noted that the applications of volumes greater than 1 gallon per acre were made by flying the area more than once. Whether these higher volumes if applied by single coverage would produce the same degree of control is open to question. Undoubtedly, better distribution of the spray is obtained where the plots are covered more than once. The question is somewhat academic at present, for with commercial spray equipment now in use on light planes, multiple coverage, or narrower swaths which would produce similar results, would be necessary to apply volumes much in excess of 1 gallon per acre.

The results of the larval spray tests provide a basis on which control recommendations can be made in the event of an epidemic outbreak of spruce budworm. In the light of this work, an oil solution spray is indicated in a concentration of between 1 and 2 pounds of DDT in 2 gallons per acre. Equipment that will produce a fairly fine spray is recommended--hollow cone spray nozzles having a 1/8-inch orifice where a centrifugal pump is used, or flat spray nozzles similar to Spraco .218F (68°) where a gear pump is used. The spray should be applied when the larvae are most exposed, and feeding out in the shoots. The period during which budworm larvae are most vulnerable to aerial sprays in the northeast is of about two weeks duration.

The sprays applied to control the moths, while reducing the population to some extent, cannot be considered as having been effectual either in materially reducing the adult population or in preventing the development of hibernating larvae. In view of these and previous results, it is doubtful if further attempts to control the moths with aerial sprays are warranted.

Further investigations on aerial spraying to control spruce budworm larvae are needed on the following points: (1) effectiveness of volatile versus nonvolatile oil solutions, (2) comparison of double versus single coverage treatments for the same dosage, (3) suitability of emulsions, and some of the newer DDT suspensions as compared with oil solutions, and (4) effectiveness of finely versus coarsely atomized sprays. The continued use of large plots, and the employment of a sampling system similar to that used

this year is considered desirable. If the needs of statistical analysis are to be met in future work, some compromise must be made between what would be statistically desirable and what is practicable for a field testing program.

REFERENCES

George, John L. and Robert T. Mitchell. 1947. The Effects of Feeding DDT-Treated Insects to Nestling Birds. Jour. Econ. Ent. 40(6):782-789.

Nagel, R. H. and J. S. Yuill. 1947. Progress Report - Field Experiments with Aerial Sprays - 1946 Season. Forest Insect Laboratory, Beltsville, Md. (ms)